

PATENT ABSTRACTS OF JAPAN

(11) Publication number : 11-176727
 (43) Date of publication of application : 02.07.1999

(51) Int.Cl. H01L 21/027
 G01B 17/00
 G03F 7/20

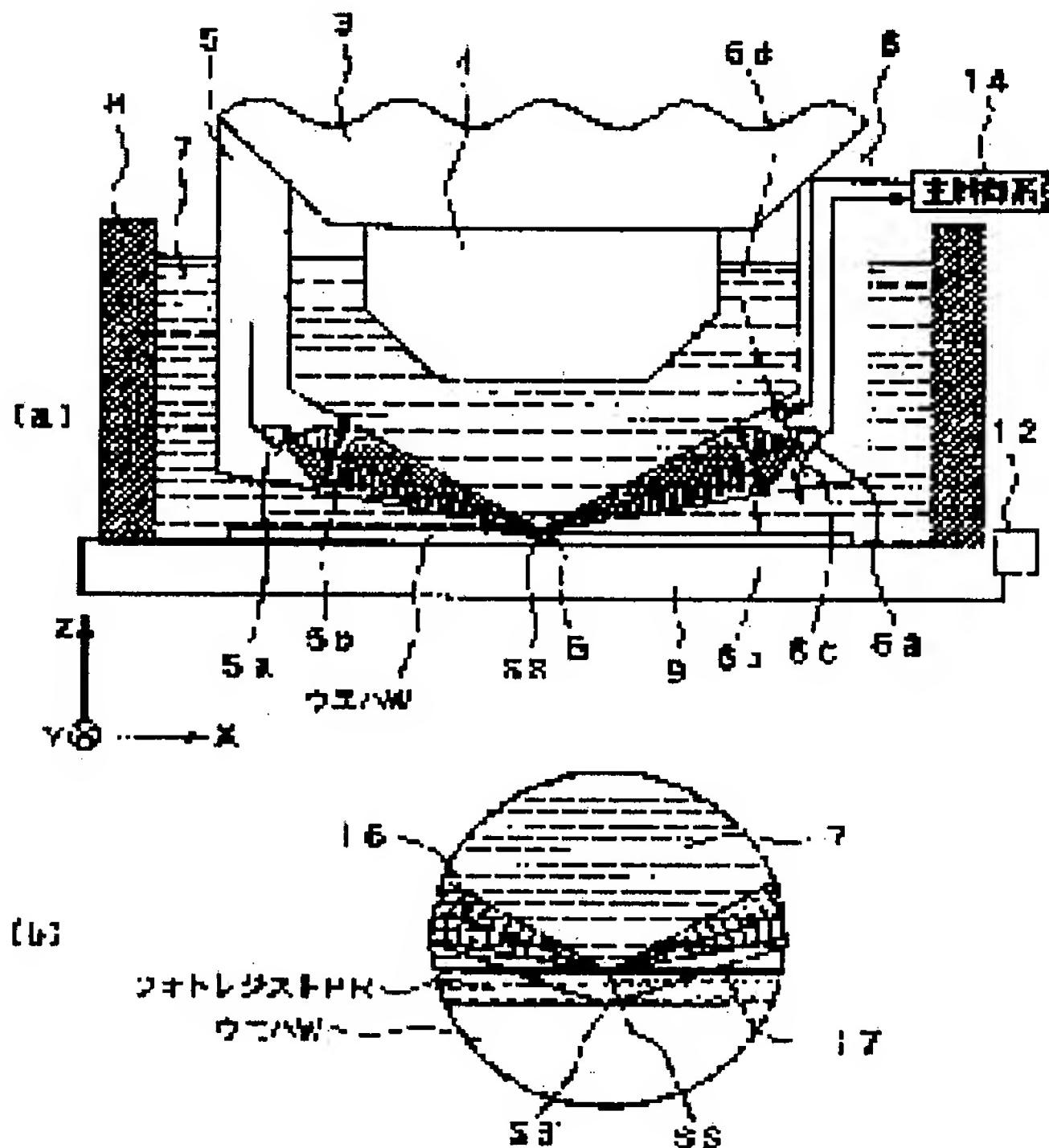
(21) Application number : 09-341445 (71) NIKON CORP
 (22) Date of filing : 11.12.1997 (72) Inventor : SHIRAISHI NAOMASA

(54) PROJECTION ALIGNER

(57) Abstract:

PROBLEM TO BE SOLVED: To detect with high precision a position in an optical axis direction of a projection optical system on a surface of a substrate, even when wavelengths of aligned lights are substantially reduced and moreover the alignment is carried out in a liquid.

SOLUTION: A liquid 7 is supplied to a sidewall 8 so as to satisfy a gap between a lens 4 of a projection optical system which is closest to a wafer W and the wafer W. Ultrasonic waves are emitted from an ultrasonic emission system 5, and the ultrasonic waves reflected by an ultrasonic focusing position SS are received by an ultrasonic reception system 6. Based on a detection signal from the ultrasonic reception system 6, a defocusing amount from a best focusing position in a focusing position SS of ultrasonic waves is acquired. Based on the acquired defocusing amount, a sample or pedestal 9 is driven in a Z-direction to control a focusing position.



[Date of request for examination]

[Date of sending the examiner's decision of rejection]

[Kind of final disposal of application other than the examiner's decision of rejection or application converted registration]

[Date of final disposal for application]

[Patent number]

[Date of registration]

[Number of appeal against examiner's decision of rejection]

[Date of requesting appeal against examiner's decision of rejection]

[Date of extinction of right]

(19) Japan Patent Office (JP)
(12) Publication of Patent Applications (A)
(11) Japanese Patent Application Kokai Publication Number: Kokai No. 11-176727
(43) Kokai Publication Date: July 2, 1999

(51) Int.Cl. ⁶	Domestic Classification Symbol	F I	
H01L 21/027		H01L 21/30	526Z
G01B 17/00		G01B 17/00	B
G03F 7/20	521	G03F 7/20	521
		H01L 21/30	514C

Request for Examination: Not yet requested. The Number of Claims: 5. (6 pages total)

(21) Application Filing Number: Patent Application No. 9-341445

(22) Application Filing Date: December 11, 1997

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(54) [Title of the Invention] PROJECTION EXPLOSION or EXPOSURE APPARATUS

(57) [Summary]

[Problem] The wavelength of an exposure light is made shorter in effect, and even in the case where the exposure is performed in a liquid, a position of the surface of a substrate along a light axis of a projection optical system is detected with high accuracy.

[Means for Solving Problem] Liquid 7 is supplied inside side wall 8 so that the space between lens 4 of the projection optical system which is located nearest to wafer W and wafer W is filled with the liquid. Ultrasonic waves are emitted from ultrasonic wave emitting system 5, and the ultrasonic waves reflected at ultrasonic wave focusing point SS are received by ultrasonic wave receiving system 6. Based on the detection signals from ultrasonic wave receiving system 6, the defocus amount from the best focus position at ultrasonic wave focusing point SS is determined. Based on the determined defocus amount, sample table 9 is driven in the Z-direction to control the focus position.

[SCOPE OF CLAIMS]

[Claim 1] A projection explosion apparatus for transferring a pattern of a mask through a projection optical system onto a substrate, said projection explosion apparatus characterized to comprise a liquid immersion device which supplies predetermined liquid on a surface of the substrate and an ultrasonic type surface position detection device which detects a position of the surface along a light axis of the projection optical system by detecting ultrasonic waves which are transmitted to the surface of the substrate through the liquid and are reflected at the surface of the substrate.

[Claim 2] A projection explosion apparatus according to claim 1, characterized in that when a photosensitive material is applied to the surface of said substrate, said surface position detection device detects the position of the surface of said photosensitive material along the light axis of said projection optical system.

[Claim 3] A projection explosion apparatus according to claim 1 or 2, characterized in that said liquid is supplied so that the space between the end portion of an optical element of said projection optical system on the side of said substrate and the surface of said substrate is filled with said liquid.

[Claim 4] A projection explosion apparatus according to claim 1, 2, or 3, characterized in that said liquid is water or organic solvent.

[Claim 5] A projection explosion apparatus according to any one of claims 1-4, characterized in that it is provided with a substrate stage that while holding said substrate, positions said substrate in a plane perpendicular to the light axis of said projection optical system and with a height control stage that based on detection results from said surface position detection device, controls the position of said substrate along the light axis of said projection optical system.

[Detailed Description of the Invention]

[0001]

[Field of Industrial Application] The present invention relates to a projection explosion or exposure apparatus used for the lithography process for manufacturing, e.g., semiconductor devices, liquid crystal devices, or thin film magnetic heads.

[0002]

[Prior Art] When manufacturing semiconductor devices, etc., there are used projection explosion apparatuses of, e.g., stepper type or step-and-scan type which transfer, via a projection optical system, an image of a pattern of a reticle, as a photomask, onto each shot area on a wafer (or a glass plate, etc.), as a substrate, to which resist is applied.

[0003] The resolution of the projection optical system provided in such a projection explosion apparatus becomes higher as the exposure wavelength used is made shorter and, also, as the numerical aperture of the projection optical system is made larger. For this reason, along with the miniaturization of integrated circuits, the exposure wavelength used for the projection explosion apparatus is becoming shorter and shorter year by year, and the numerical aperture of the projection optical system is also becoming larger and larger. In this context, the presently dominant exposure wavelength is 248 nm from a KrF excimer laser, but the use of a still shorter wavelength of 193 nm from an ArF excimer laser is now being considered.

[0004] In addition, when performing exposure, the depth of focus (DOF) is an important factor along with the resolution. The resolution R and the depth of focus δ are respectively expressed by the following formulas:

$$R = k_1 \cdot \lambda / NA, \quad (1)$$

$$\delta = k_2 \cdot \lambda / NA^2, \quad (2)$$

where λ is the exposure wavelength, NA is the numerical aperture of the projection optical system, and k_1 and k_2 are process coefficients. Assuming the case where an identical resolution is obtained, a larger depth of focus can be obtained as an exposure light of a shorter wavelength is used. However, when considering the spectral transmittance characteristics of transmitting optical members (glass materials) used for projection optical systems, there are at the

present time scarcely any glass materials through which an exposure light having a wavelength shorter than 193 nm of an ArF excimer laser can transmit and which can at the same time form a relatively large lens.

[0005]

[Problem to Be Solved by the Invention] As described above, with respect to the conventional projection explosion apparatuses (projection optical systems), it is difficult to use an exposure light having a wavelength shorter than 193 nm of an ArF excimer laser. To address this problem, the liquid immersion method has been proposed as a method to make the exposure wavelength shorter in effect. This is designed to, by immersing a wafer in a predetermined liquid and thus by taking advantage of the fact that the wavelength of the exposure light in the liquid becomes $1/n$ times (n is the refractive index of the liquid and is generally about 1.2 to 1.6) of that in the air, improve the resolution and increase the depth of focus.

[0006] By the way, since it is required that during exposure, the entirety of the exposure region be within the range of the depth of focus of the projection optical system, a focusing mechanism (autofocus mechanism) is provided in the projection explosion apparatus. This mechanism is generally configured such that a light beam is incident with an oblique incidence angle on the surface of a wafer to be exposed, the reflected light thereof is received by an opposite optical system to detect the focus condition of the wafer surface, and by moving the wafer vertically to adjust it to the focus position.

[0007] A photosensitive film (photoresist) is applied to the wafer surface to be exposed, and onto this photoresist is transferred the pattern. It is therefore preferable that the photoresist surface is made coincide with the focus position of the projection optical system, and thus it is required that the position of the photoresist surface be detected. In the conventional projection explosion apparatuses, the space where the wafer is placed is filled with a gas, e.g., air or nitrogen. In this regard, for example, the refractive index of air is 1, and the refractive index of the photoresist applied to the wafer surface is approximately 1.7. Thus, the light reflectance at the air/photoresist interface can be calculated by the Fresnel equations as follows:

$$\begin{aligned} \text{Reflectance} &= \{(1-1.7)/(1+1.7)\}^2 \times 100 \\ &= 6.7 (\%). \end{aligned} \tag{3}$$

A relatively large amount of the light beams for the focus detection is reflected at the air/photoresist interface, and thus the photoresist surface position can be detected.

[0008] However, in the case of a projection explosion apparatus in which the liquid immersion method is adopted, it will be configured such that the space where a wafer is placed is filled with a liquid. In the case where the liquid is, for example, water, its refractive index is 1.3, and the light reflectance at the water/photoresist interface can be calculated by the Fresnel equations as follows:

$$\begin{aligned} \text{Reflectance} &= \{(1.3-1.7)/(1.3+1.7)\}^2 \times 100 \\ &= 1.8 (\%). \end{aligned} \tag{4}$$

Since compared with the air/photoresist interface, the differential between the refractive index of the space and that of the photoresist becomes significantly small at the water/photoresist interface, the reflectance of the light beams for the focus detection decreases, which makes it difficult to precisely detect the photoresist surface position.

[0009] In consideration of such situations, an object of the present invention is to provide a projection explosion or exposure apparatus in which the wavelength of the exposure light is made smaller in effect and which can transfer even finer patterns. Further, it is also an object to provide a projection explosion apparatus that even in the case where exposure is performed on a substrate over which a photosensitive material is applied, can detect with high accuracy the position of

the surface of the photosensitive material along the light axis of the projection optical system.

[0010]

[Means for Solving the Problems] A projection explosion apparatus of the present invention is a projection explosion apparatus for transferring a pattern of a mask (R) through a projection optical system (PL) onto a substrate (W), the projection explosion apparatus characterized to comprise a liquid immersion device (2, 8) which supplies predetermined liquid (7) on a surface of the substrate (W) and an ultrasonic type surface position detection device (5, 6) which detects a position of the surface along a light axis of the projection optical system (PL) by detecting ultrasonic waves which are transmitted to the surface of the substrate through the liquid (7) and are reflected at the surface of the substrate.

[0011] In accordance with such projection explosion apparatus of the present invention, since the pattern of the mask (R) is exposed onto the surface of the substrate (W) via the liquid (7), the wavelength of the exposure light at the surface of the substrate can be made smaller in effect, with the wavelength becoming $1/n$ times (n is the refractive index of the liquid (7)) of that in the air. Further, since the position of the surface of the substrate (W) along the light axis is detected with high accuracy by the ultrasonic type surface position detection device (5, 6), the position can be detected with high accuracy even in liquid (7) in which it is difficult to detect the surface position by an optical type surface position detection device.

[0012] Further, it is preferable that when a photosensitive material (PR) is applied to the surface of the substrate (W), the surface position detection device (5, 6) detects the position of the surface of the photosensitive material (PR) along the light axis of the projection optical system (3, 4). In this case, the image surface of the projection optical system (3, 4) can be adjusted to the surface of the photosensitive material (PR). Further, it is preferable that the liquid (7) is supplied so that the space between the end portion of an optical element (4) of the projection optical system (PL) on the side of the substrate (W) and the surface of the substrate (W) is filled with the liquid. In this case, the wavelength of the exposure light at the surface of the substrate (W) can be made smaller in effect, with the wavelength becoming $1/n$ times (n is the refractive index of the liquid (7)) of that in the air. Further, since the lens barrel (3) of the projection optical system (PL) does not come into contact with the liquid (7), there is the advantage that the lens barrel (3) of the projection optical system (PL) becomes unlikely to be corroded.

[0013] Further, the liquid (7) is water (having a refractive index of 1.3) or organic solvent (e.g., alcohol (e.g., ethanol (having a refractive index of 1.36) or cedar oil (having a refractive index of 1.52)). In this case, when water is used as the liquid (7), there is the advantage that it is easily available. Further, when organic solvent is used as the liquid (7), there is the advantage that the lens barrel (3) of the projection optical system (PL) becomes unlikely to be corroded. Still further, when cedar oil is used as the liquid (7), it has a large refractive index of about 1.5, and thus the wavelength of the exposure light can be made still smaller in effect.

[0014] Further, it is preferable that the projection explosion apparatus is provided with a substrate stage (10) that while holding the substrate (W), positions the substrate (W) in a plane perpendicular to the light axis of the projection optical system (PL) and with a height control stage (9) that based on detection results from the surface position detection device (5, 6), controls the position of the substrate (W) along the light axis (3, 4) of the projection optical system. In this case, the surface of the substrate (W) can be adjusted with high accuracy relative to the image surface of the projection optical system (3, 4).

[0015]

[Embodiment of the Invention] In the following, an embodiment of the present invention will be described referring to FIGS. 1-3. FIG. 1(a) shows an outline configuration of the projection explosion or exposure apparatus of the embodiment; in FIG. 1(a), illumination light IL constituted by ultraviolet pulse

light of 193 nm wavelength emitted from illumination optical system 1 including an ArF excimer laser as the exposure light source, an optical integrator, a field stop, a condenser lens, etc. illuminates a pattern provided on reticle R. The pattern of reticle R is, via projection optical system PL that is telecentric on both sides (or one-side telecentric on the wafer side), reduction projected with projection magnification β (β being, e.g., 1/4 or 1/5) onto an exposure area on the wafer W on which photoresist PR is applied. It is to be noted that as illumination light IL, KrF excimer laser light (248 nm wavelength), F₂ excimer laser light (157 nm wavelength), the i-line of a mercury lamp, etc. may be used. In the following, description will be made by setting the Z-axis parallel to light axis AX of projection optical system PL and by, in a plane perpendicular to the Z-axis direction, setting the Y-axis along the direction perpendicular to the plane of the drawing of FIG. 1(a) and setting the X-axis along the direction parallel to the plane of the drawing.

[0016] Reticle R is held on reticle stage RST; in reticle stage RST is incorporated a mechanism that can finely move in the X-direction, the Y-direction, and the rotational direction. The two-dimensional position and rotation angle of reticle stage RST are being measured in real time by a laser interferometer (not shown). On the other hand, wafer W is held, via a wafer holder (not shown), on sample table 9; sample table 9 is fixed on Z-stage 10 that controls the focus position (the position in the Z-direction) and inclination angle of wafer W. On sample table 9 is provided a cylinder-shaped side wall 8, and the inside thereof is filled with liquid 7. Liquid 7 is, by liquid supply/recovery system 2 constituted by a pump, etc., supplied to the inside of side wall 8 before an exposure process and recovered after the exposure process, via nozzle 2a. It should be noted that in the projection explosion apparatus of the embodiment, water (having a refractive index of 1.3) is used as liquid 7, and the wavelength of the light in the water becomes 1/1.3 times of that in the air, so that the wavelength of the exposure light from the ArF excimer laser is made shorter in effect, i.e., to be approximately 148 nm.

[0017] Further, lens barrel 3 of projection optical system PL is made of metal, and to prevent the lens barrel from being corroded by liquid 7, the contact portion of projection optical system PL with liquid 7 is restricted exclusively to lens 4 located nearest to wafer W. Further, on the side surface of lens barrel 3 of projection optical system PL is attached a focus position detection system (hereinafter, referred to as "AF sensor 5, 6") constituted by ultrasonic wave emitting system 5 and ultrasonic wave receiving system 6.

[0018] FIG. 1(b) is an enlarged view illustrating side wall 8 and its vicinity of FIG. 1(a); in FIG. 1(b), to side wall 8 is provided an openable-closable door 8a that is used when wafer W is conveyed on sample table 9 or is carried out of sample table 9. Further, nozzle 2a of liquid supply/recovery system 2 is configured such that it can be vertically driven when the liquid is supplied or recovered.

[0019] Returning to FIG. 1(a), Z-stage 10 is fixed on XY-stage 11 that moves along the XY-plane that is parallel to the image surface of projection optical system PL, and XY-stage 11 is mounted on a base, not shown. By controlling the focus position (the position in the Z-direction) and inclination angle of wafer W, Z-stage 10 adjusts the surface of photoresist PR on wafer W to the image surface of projection optical system PL by means of an autofocus system and an autoleveling system; XY-stage 11 performs the positioning of wafer W in the X- and Y-directions. The two-dimensional position and rotation angle of sample table 9 (w) are being measured as the position of moving mirror 12 in real time by laser interferometer 13. With based on the measurement results, control information being sent from main control system 14 to wafer stage drive system 15, the operations of Z-stage 10 and XY-stage 11 are controlled; when exposure is to be performed, each of the shot areas on wafer W sequentially moves to the exposure position, and the pattern of reticle R is exposure-transferred to each shot area.

[0020] Next, the AF sensor 5, 6 of the embodiment will be described. FIG. 2(a) shows in an enlarged scale the lower part of the projection optical system of the embodiment and its vicinity; in FIG. 2(a), ultrasonic wave emitting system 5 is

provided with ultrasonic wave generating device 5a and ultrasonic wave focusing device 5b. Ultrasonic waves with a frequency of about from 50 MHz to 500 MHz having been emitted from ultrasonic wave generating device 5a constituted by piezoelectric device, etc. are focused by ultrasonic wave focusing device 5b on focusing point SS on the surface of photoresist PR applied to wafer W, are reflected at focusing point SS, and enter ultrasonic wave receiving system 6. Ultrasonic wave receiving system 6 is provided with ultrasonic wave receiving device 6a, ultrasonic wave focusing device 6b, and sound insulating plate 6c that can vibrate; the ultrasonic waves having entered ultrasonic wave receiving system 6 are focused by ultrasonic wave focusing device 6b and enter, via an opening of sound insulating plate 6c, ultrasonic wave receiving device 6a. Detection signals from ultrasonic wave receiving device 6a are supplied to main control system 14. It is to be noted that the opening, which makes ultrasonic waves pass therethrough, is provided in the center portion of sound insulating plate 6c, and main control system 14, by laterally shifting (or vibrating) sound insulating plate 6c by means of sound insulating plate drive mechanism 6d, detects the position where the detection signal of ultrasonic wave receiving device 6a becomes maximum. Alternatively, the detection signal of ultrasonic wave receiving device 6a may be synchronously detected with a signal synchronized with the signal by which sound insulating plate 6c is vibrated.

[0021] Figure 2(b) shows the enlarged view of the vicinity of the focusing point SS of ultrasonic waves on the surface of the photoresist PR, and in this figure 2(b), the photoresist PR for photosensitization is applied on the wafer W. Even if the position SS of the surface of the photoresist PR are tried to be detected by the AF sensor of the conventional optical-type and the oblique incidence-type, the refractive index of the liquid 7 and that of the photoresist PR are almost equivalent so that the reflectance becomes extremely low. Therefore the position SS' to be detected is not placed on the surface of the photoresist PR, and the image surface of the projection optical system PL is adjusted to the surface of the substrate of the wafer W itself. The ultrasonic waves of the AF sensors 5, 6 in this example go along the pass 16 and are reflected at the surface of the photoresist PR. Therefore the position SS on the surface of the photoresist PR is detected precisely and the surface of the photoresist PR can be focused onto the image surface with high precision.

[0022] In addition, the Z-direction position of the surface of photoresist PR is, in accordance with the principle of the AF sensor of the conventional optical-type and the oblique incidence-type, detected from the lateral shift amount of the ultrasonic wave focusing position on ultrasonic wave receiving device 6a. More specifically, since if wafer W shifts downwardly (in the Z-direction) in FIG. 2(b), then the focusing position on ultrasonic wave receiving device 6a in FIG. 2(a) shifts upwardly and since if wafer W shifts upwardly in FIG. 2(b), then the focusing position on ultrasonic wave receiving device 6a shifts downwardly, the focus position change amount of the surface of photoresist PR can be determined by the lateral shift amount. To this end, it would suffice to determine in advance the best focus position by means of, e.g., a test print and then to, at that time, make the opening center (or the vibration center) of sound insulating plate 6c coincide with the center of the ultrasonic wave focusing position.

[0023] FIG. 3 shows, by way of an example, the relationship between focus signal D obtained by synchronously detecting the detection signal from ultrasonic wave receiving system 6 and the focus position Z of the surface of photoresist PR. In main control system 14, with the detection signals from ultrasonic wave receiving device 6a being synchronously rectified with the drive signal of sound insulating plate 6c, focus signal D that changes in approximate proportion to focus position Z in a predefined range is generated in correspondence with the ultrasonic wave focusing point SS on the surface of photoresist PR. In the embodiment, focus signal D, which corresponds to the ultrasonic wave focusing point SS, is calibrated so that it becomes zero when focusing point SS coincide with the image surface (best focus position) of projection optical system PL, and thus main control system 14 can determine the

defocus amount (shift amount) by way of focus signal D. Exposure is to be performed by moving Z-stage 10 (wafer W) downwardly when the focus position of wafer W is located above the reference position and by moving Z-stage 10 (wafer W) upwardly when the focus position of wafer W is, in contrast, located below the reference position.

【0024】 It is to be noted that while, in the embodiment, water (having a refractive index of 1.3) is used as liquid 7, organic solvent (e.g., alcohol or cedar oil) may also be used as liquid 7. In this case, there is the advantage that the lens barrel 3 of the projection optical system PL becomes unlikely to be corroded. Further, when cedar oil (having a refractive index of 1.5) is used, it has a large refractive index of about 1.5, and thus the wavelength of the exposure light can be made still smaller in effect.

【0025】 In addition, with respect to the focus position detection, it may also be configured such that by disposing a sound insulating plate having a plurality of openings in ultrasonic wave emitting system 5, each of the focus positions at a plurality of points on the photoresist surface is detected or such that by disposing a sound insulating plate having a large opening in ultrasonic wave emitting system 5 and by, at the same time, disposing a sound insulating plate having a plurality of openings in ultrasonic wave receiving system 6, each of the focus positions at a plurality of points is similarly detected.

【0026】 Further, while, in the above-described embodiment, the focus position of the surface of the photoresist of the wafer is detected by using ultrasonic waves, a leveling sensor that detects the inclination angle of the surface of the photoresist by using ultrasonic waves may also be used. In this leveling sensor, it would suffice to irradiate ultrasonic waves that proceed almost parallel to the wafer surface and to detect the sound collecting position of the ultrasonic waves reflected.

【0027】 It should be noted that needless to say, the present invention is not limited to the above-described embodiment but can have various configurations within the scope not departing from the essence of the present invention.

【0028】 **[Effect of the Invention]** In accordance with the projection explosion or exposure apparatus of the present invention, since the image of a mask pattern is exposed, via liquid, onto the surface of a substrate, the wavelength of the exposure light at the surface of the substrate can be made smaller in effect, with the wavelength becoming the inverse number-times of the refractive index of the liquid of that in the air. Further, since the position of the surface of the substrate along the light axis is detected with high accuracy by an ultrasonic type surface position detection device, the position can be detected with high accuracy even in liquid in which it is difficult to detect the surface position by an optical type surface position detection device.

【0029】 Further, in the case where the surface position detection device detects the position of the surface of a photosensitive material along the light axis of the projection optical system, the surface of the photosensitive material can be adjusted with high accuracy to the image surface of the projection optical system based on the detection information. Further, in the case where the liquid is supplied so that the space between the end portion of an optical element of the projection optical system on the side of the substrate and the surface of the substrate is filled with the liquid, the wavelength of the exposure light can be made smaller in effect, with the wavelength becoming $1/n$ times (n is the refractive index of the liquid) of that in the air. Further, since the lens barrel of the projection optical system does not come into contact with the liquid, there is the advantage that the lens barrel of the projection optical system becomes unlikely to be corroded.

【0030】 Further, when the liquid is water, there is the advantage that it is easily available. When the liquid is organic solvent (e.g., alcohol or cedar oil), there is the advantage that the lens barrel of the projection optical system is unlikely to be corroded. Still further, when cedar oil is used as the liquid, it has a larger refractive index of about 1.5 compared with, e.g., water (having a refractive index of 1.3), and thus the wavelength of the exposure light can be made still smaller in

effect.

[0031] Further, in the case where the projection explosion apparatus is provided with a substrate stage that while holding the substrate, positions the substrate in a plane perpendicular to the light axis of the projection optical system and with a height control stage that based on detection results from the surface position detection device, controls the position of the substrate along the light axis of the projection optical system, the image surface of the projection optical system can be adjusted with high accuracy to the exposure position on the surface of the substrate.

[Brief Description of the Drawings]

[FIG. 1] (a) is an outline configuration drawing showing a projection explosion apparatus embodiment example of the present invention; (b) is an enlarged view illustrating side wall 8 and its vicinity of FIG. 1(a).

[FIG. 2] (a) is a partial enlarged view showing the configuration of the lower part of the projection explosion apparatus; (b) is an enlarged view of the B portion of FIG. 2(a).

[FIG. 3] This is a drawing showing the relationship between the focus position Z of the surface of the photoresist on wafer W and focus signal D.

[Explanations of Letters or Numerals]

W wafer

R reticle

PL projection optical system

1 illumination optical system

2 liquid supply/recovery system

3 lens barrel

4 lens

5 ultrasonic wave emitting system

6 ultrasonic wave receiving system

7 liquid

8 side wall

9 sample table

10 Z-stage

14 main control system

15 wafer stage drive system

(19) 日本国特許庁 (JP)

(12) 公開特許公報 (A)

(11) 特許出願公開番号

特開平11-176727

(43) 公開日 平成11年(1999)7月2日

(51) Int.Cl.⁶

H 01 L 21/027
G 01 B 17/00
G 03 F 7/20

識別記号

5 2 1

F I

H 01 L 21/30 5 2 6 Z
G 01 B 17/00 B
G 03 F 7/20 5 2 1
H 01 L 21/30 5 1 4 C

審査請求 未請求 請求項の数 5 O L (全 6 頁)

(21) 出願番号

特願平9-341445

(22) 出願日

平成9年(1997)12月11日

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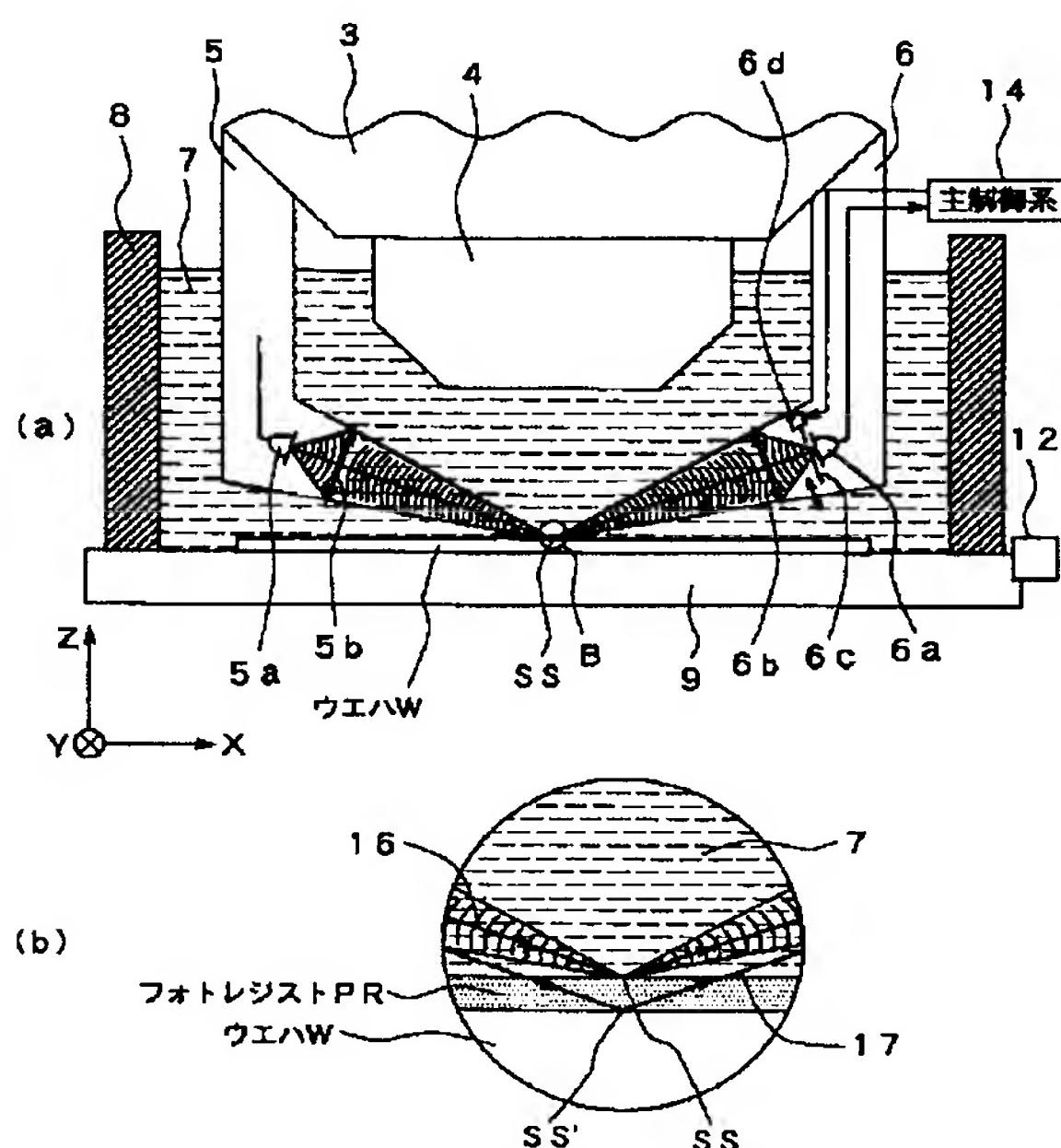
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(54) 【発明の名称】 投影露光装置

(57) 【要約】

【課題】 露光光を実質的に短波長化し、また、露光が液体中で行われる場合であっても、基板表面の投影光学系の光軸方向の位置を高精度に検出する。

【解決手段】 ウエハWに最も近い投影光学系のレンズ4とウエハWとの間を満たすように側壁8内に液体7を供給する。超音波射出系5から超音波を射出し、超音波集束位置SSにおいて反射した超音波を超音波受信系6により受信する。超音波受信系6からの検出信号に基づいて、超音波の集束位置SSにおけるベストフォーカス位置からのデフォーカス量を求める。求められたデフォーカス量に基づいて試料台9をZ方向に駆動し、フォーカス位置の制御を行う。



*ページと、を備えたことを特徴とする請求項1～4の何れか一項記載の投影露光装置。

【発明の詳細な説明】

【0001】

【発明の属する技術分野】本発明は、例えば、半導体素子、液晶表示素子、又は薄膜磁気ヘッド等を製造するためのリソグラフィ工程に用いられる投影露光装置に関する。

【0002】

【従来の技術】半導体素子等を製造する際に、フォトマスクとしてのレチクルのパターンの像を投影光学系を介して、基板としてのレジストが塗布されたウエハ（又はガラスプレート等）上の各ショット領域に転写するステッパー型、又はステップ・アンド・スキャン方式等の投影露光装置が使用されている。

【0003】投影露光装置に備えられている投影光学系の解像度は、使用する露光波長が短く、投影光学系の開口数が大きいほど高くなる。そのため、集積回路の微細化に伴い投影露光装置で使用される露光波長は年々短波長化しており、投影光学系の開口数も増大してきている。そして、現在主流の露光波長は、ArFエキシマレーザの248nmであるが、更に短波長のArFエキシマレーザの193nmの使用も検討されている。

【0004】また、露光を行う際には、解像度と同様に焦点深度も重要なとなる。解像度R、及び焦点深度δはそれぞれ以下の式で表される。

$$(1) R = k_1 \cdot \lambda / NA$$

$$(2) \delta = k_2 \cdot \lambda / NA^2$$

ここで、λは露光波長、NAは投影光学系の開口数、 k_1 、 k_2 はプロセス係数である。同じ解像度を得る場合には短い波長の露光光を用いた方が大きな焦点深度を得ることができる。しかしながら、投影光学系に使用される透過性の光学部材（硝材）の分光透過特性を考慮すると、現時点ではArFエキシマレーザの193nmより短い波長の露光光を透過できると共に、比較的大きなレンズを形成できる均一な硝材はほとんどない。

【0005】

【発明が解決しようとする課題】上記の如く従来の投影露光装置（投影光学系）では、ArFエキシマレーザの193nmより短い波長の露光光を使用することは困難である。そこで、実質的に露光波長を短くする方法として、液浸法が提案されている。これは、ウエハを所定の液体中に浸し、液体中の露光光の波長が、空気中の $1/n$ 倍（nは液体の屈折率で通常1.2～1.6程度）になることを利用して解像度を向上し、焦点深度を増大するというものである。

【0006】ところで、露光時には、露光範囲全体が投

$$\text{反射率} = \{ (1 - 1.7) / (1 + 1.7) \}^2 \times 100 \\ = 6.7\% \quad (1)$$

空気-フォトレジスト界面では、合焦検出用の光束の比

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*影光学系の焦点深度の範囲内に入る必要があるため、投影露光装置には、合焦機構（オートフォーカス機構）が設けられている。これは、一般に露光すべきウエハの表面に斜入射で光ビームを入射し、その反射光を対面の光学系で受光してウエハ表面の合焦状態を検出し、ウエハを上下に移動して合焦位置へ追い込むというものである。

【0007】露光されるウエハ表面には感光膜（フォトレジスト）が塗布されており、このフォトレジストにパターンが転写される。そこで、このフォトレジスト表面を投影光学系の焦点位置に一致させることが望ましく、

フォトレジスト表面の位置を検出する必要がある。従来の投影露光装置では、ウエハが配置される空間は空気、又は窒素等の気体で満たされている。そして、例えば空気の屈折率は1であり、ウエハ表面に塗布されたフォトレジストの屈折率は、約1.7である。従って、空気-フォトレジスト界面における光の反射率は、フレネルの式より以下のように計算される。

$$(3)$$

較的多くが反射し、フォトレジスト表面の位置を検出す

ることができる。

【0008】しかし、液浸法を採用した投影露光装置の場合には、ウェハが配置される空間は液体で満たされる*

$$\text{反射率} = \{(1.3 - 1.7) / (1.3 + 1.7)\}^2 \times 100 \\ = 1.8\% \quad (3)$$

水-フォトトレジスト界面では、空気-フォトトレジスト界面に比べ空間とフォトトレジストとの屈折率の差が著しく小さくなるため、合焦検出用の光束の反射率が低下し、フォトトレジスト表面の位置を正確に検出することが困難となる。

【0009】本発明は斯かる点に鑑み、露光光の波長を短波長化し、より微細なパターンを転写できる投影露光装置を提供することを目的とする。さらに、液体中に感光材料が塗布された基板上に露光が行われる場合であっても、その感光材料の表面の投影光学系の光軸方向の位置を高精度に検出することができる投影露光装置を提供することをも目的とする。

【0010】

【課題を解決するための手段】本発明の投影露光装置は、マスク(R)のパターン像を投影光学系(PL)を介して基板(W)上に転写する投影露光装置において、その基板(W)の表面に所定の液体(7)を供給する液浸装置(2, 8)と、その基板(W)の表面に液体

(7)を介して超音波を送出し、その表面で反射される超音波を検出することによってその表面のその投影光学系(PL)の光軸方向の位置を検出する超音波方式の面位置検出装置(5, 6)とを備えたものである。

【0011】斯かる本発明の投影露光装置によれば、マスク(R)のパターン像を液体(7)を介して基板

(W)の表面に露光するため、基板表面における露光光の波長を空气中における波長の1/n倍(nは液体(7)の屈折率)に短波長化できる。また、超音波方式の面位置検出装置(5, 6)により基板(W)の表面の光軸方向の位置を高精度に検出するため、光学式の面位置検出装置では面位置の検出が困難な液体(7)中においても、その位置を高精度に検出することができる。

【0012】また、基板(W)の表面に感光材料(PR)が塗布されている際に、面位置検出装置(5, 6)は、その感光材料(PR)の表面の投影光学系(3, 4)の光軸方向の位置を検出することが望ましい。この場合、投影光学系(3, 4)の像面をその感光材料(PR)の表面に合わせ込むことができる。また、投影光学系(PL)の基板(W)側の光学素子(4)の先端部と

その基板(W)の表面との間を満たすように液体(7)が供給されることが望ましい。この場合、基板(W)表面における露光光の波長を、空气中における露光光の波長の1/n倍(nは液体(7)の屈折率)に短波長化できる。さらに、投影光学系(PL)の鏡筒(3)が液体(7)に接触しないため、鏡筒(3)が腐食しにくくなるという利点がある。

*ことになる。例えば液体が水である場合、その屈折率は1.3であり、水-フォトトレジスト界面における光の反射率は、フレネルの式より以下のように計算される。

$$\text{反射率} = \{(1.3 - 1.7) / (1.3 + 1.7)\}^2 \times 100 \quad (3)$$

(4)

【0013】また、その液体(7)は、水(屈折率1.3)、又は有機溶媒(例えばアルコール(エタノール(屈折率1.36)等)、セダー油(屈折率1.52)等)である。この場合に液体(7)として水を用いる場合には、その入手が容易であるという利点がある。また、液体(7)として有機溶媒を用いる場合には、投影光学系(PL)の鏡筒(3)が腐食しにくくなるという利点がある。さらに、液体(7)としてセダー油を用いる場合には、その屈折率が約1.5と大きく、露光光をより短波長化することができる。

【0014】また、基板(W)を保持してこの基板(W)を投影光学系(PL)の光軸に垂直な平面上で位置決めする基板ステージ(10)と、面位置検出装置(5, 6)の検出結果に基づいてその基板(W)の投影光学系の光軸方向(3, 4)の位置を制御する高さ制御ステージ(9)とを備えることが望ましい。この場合、投影光学系(3, 4)の像面に対して基板(W)の表面を高精度に合わせ込むことができる。

【0015】

【発明の実施の形態】以下、本発明の実施の形態の一例につき図1～図3を参照して説明する。図1(a)は本例の投影露光装置の概略構成を示し、この図1(a)において、露光光源としてのArFエキシマレーザ光源、オプティカル・インテグレータ、視野絞り、コンデンサレンズ等を含む照明光学系1から射出された波長193nmの紫外バルス光よりなる露光光ILは、レチクルRに設けられたパターンを照明する。レチクルRのパターンは、両側(又はウェハ側に片側)テレセントリックな投影光学系PLを介して所定の投影倍率β(βは例えば1/4, 1/5等)でフォトトレジストPRが塗布されたウェハW上の露光領域に縮小投影される。なお、露光光ILとしては、KrFエキシマレーザ光(波長248nm)、F₂エキシマレーザ光(波長157nm)や水銀ランプのi線(波長365nm)等を使用してもよい。以下、投影光学系PLの光軸AXに平行にZ軸を取り、Z軸に垂直な平面内で図1(a)の紙面に垂直な方向に沿ってY軸を取り、紙面に平行な方向に沿ってX軸を取って説明する。

【0016】レチクルRはレチクルステージRST上に保持され、レチクルステージRSTにはX方向、Y方向、回転方向に微動できる機構が組み込まれている。レチクルステージRSTの2次元的な位置、及び回転角はレーザ干渉計(不図示)によってリアルタイムに計測されている。一方、ウェハWはウェハホルダ(不図示)を介して試料台9上に保持され、試料台9はウェハWのフ

オーカス位置（Z方向の位置）及び傾斜角を制御するZステージ10上に固定されている。試料台9上には円筒状の側壁8が設けられおり、その内部は液体7で満たされている。液体7は、ポンプ等からなる液体供給回収系2により、ノズル2aを介して露光前に側壁8内に供給され、露光後に回収される。なお、本例の投影露光装置では液体7として水（屈折率1.3）を使用しており、光の波長は水中において空気中の1/1.3倍になるため、ArFエキシマレーザ（波長193nm）よりなる露光光の波長は実質的に約148nmに短波長化される。

【0017】また、投影光学系PLの鏡筒3は金属製であり、液体7による腐食を防止するため、本例では、投影光学系PLと液体7との接触部分は、ウエハWに最も近いレンズ4のみとしている。また、投影光学系PLの鏡筒3の側面には、超音波射出系5と超音波受信系6となりなる焦点位置検出系（以下「AFセンサ5, 6」と呼ぶ）が取り付けられている。

【0018】図1（b）は図1（a）の側壁8近傍の拡大図であり、この図1（b）において、側壁8にはウエハWの試料台9への搬送、又は試料台9からの搬出の際に使用する開閉自在の扉8aが設けられている。また、液体供給回収系2のノズル2aは、液体の供給、及び回収の際に上下に駆動することができる構成となっている。

【0019】図1（a）に戻り、Zステージ10は投影光学系PLの像面と平行なXY平面に沿って移動するXYステージ11上に固定され、XYステージ11は不図示のベース上に載置されている。Zステージ10は、ウエハWのフォーカス位置（Z方向の位置）、及び傾斜角を制御してウエハW上のフォトレジストPR表面をオートフォーカス方式、及びオートレベリング方式で投影光学系PLの像面に合わせ込み、XYステージ11はウエハWのX方向、及びY方向の位置合わせを行う。試料台9（ウエハW）の2次元的な位置、及び回転角は、移動鏡12の位置としてレーザ干渉計13によってリアルタイムに計測されている。この計測結果に基づいて主制御系14からウエハステージ駆動系15に制御情報が送られ、Zステージ10、XYステージ11の動作が制御され、露光時にはウエハW上の各ショット領域が順次露光位置に移動し、レチクルRのパターンが各ショット領域へ露光転写される。

【0020】次に、本例の投影露光装置のAFセンサ5, 6について説明する。図2（a）は、本例の投影光学系の下部近傍を拡大して示し、この図2（a）において、超音波射出系5には超音波発生素子5a、及び超音波集束素子5bが設けられている。圧電素子等からなる超音波発生素子5aから射出された周波数50MHz～200MHz程度の超音波は、超音波集束素子5bによりウエハWに塗布されたフォトレジストPR表面上の集

束位置SSに集束され、集束位置SSで反射して超音波受信系6に入射する。超音波受信系6には超音波受信素子6a、超音波集束素子6b、及び振動できる遮音板6cが設けられており、超音波受信系6に入射した超音波は超音波集束素子6bにより集束され、遮音板6cの開口を介して超音波受信素子6aに入射する。超音波受信素子6aの検出信号は主制御系14に供給される。なお、遮音板6cの中央部には超音波を通過させる開口が設けられて、主制御系14が遮音板駆動機構6dにより遮音板6cを横シフト（又は振動）させて超音波受信素子6aの検出信号が最大になる位置を検出する。又は、遮音板6cを振動させるのに同期した信号で超音波受信素子6aの検出信号を同期検波してもよい。

【0021】図2（b）は、フォトレジストPR表面上の超音波の集束位置SS付近を拡大して示し、この図2（b）において、ウエハW上には感光用のフォトレジストPRが塗布されている。従来の光学式で斜入射方式のAFセンサによりフォトレジストPR表面上の位置SSを検出しようとしても、液体7とフォトレジストPRの屈折率が同程度で反射率が極めて低くなり、光は経路17に沿ってウエハWの表面まで進むため、検出される位置SS'はフォトレジストPRの表面上に位置せず、投影光学系PLの像面にはウエハWの基板自体の表面が合わせ込まれる。本例のAFセンサ5, 6の超音波は経路16に沿って進みフォトレジストPRの表面で反射されるため、フォトレジストPR表面上の位置SSが正確に検出され、高精度にフォトレジストPR表面を像面に合焦させることができる。

【0022】また、フォトレジストPR表面のZ方向の位置は、従来の光学式で斜入射方式のAFセンサと同様の原理によって超音波受信素子6a上での超音波の集束位置の横シフト量から検出される。即ち、ウエハWが図2（b）中の下方（-Z方向）にずれれば図2（a）の超音波受信素子6a上での集束位置が上方にずれ、ウエハWが図2（b）中の上方にずれれば超音波受信素子6a上での集束位置は下方にずれるため、この横シフト量よりフォトレジストPRの表面のフォーカス位置の変化量を求めることができる。そのため、予めベストフォーカス位置はテストプリント等によって定めておき、そのときに遮音板6cの開口の中心（又は振動中心）と超音波の集束位置の中心とを合わせておけばよい。

【0023】図3は、一例として超音波受信系6からの検出信号を同期検波して得られるフォーカス信号DとフォトレジストPR表面のフォーカス位置Zとの関係を示す。主制御系14内で、超音波受信装置6aからの検出信号を、遮音板6cの駆動信号で同期整流することによって、フォトレジストPR表面での超音波の集束位置SSに対応して、フォーカス位置Zに所定範囲でほぼ比例して変化するフォーカス信号Dが生成される。本例では、超音波の集束位置SSに対応するフォーカス信号D

は、集束位置SSが投影光学系PLの像面（ベストフォーカス位置）に合致しているときになりのようにキャリブレーションが行われており、主制御系14は、フォーカス信号Dよりデフォーカス量（ずれ量）を求めることができる。ウェハWのフォーカス位置が上方にある場合には、Zステージ10（ウェハW）を下方に移動し、逆にフォーカス位置が下方にある場合には、Zステージ10（ウェハW）を上方に移動して露光を行うことになる。

【0024】なお、本例では液体7として水（屈折率1.3）を使用したが、液体7として有機溶媒（例えばアルコール、セダー油等）を用いることもできる。この場合には、投影光学系PLの鏡筒3が腐食しにくくなるという利点がある。また、セダー油（屈折率1.5）を用いる場合には、その屈折率が1.5と大きく、露光光を実質的に短波長化することができる。

【0025】なお、フォーカス位置の検出については、超音波射出系5に複数の開口を有する遮音板を配置し、フォトレジスト表面の複数点での各フォーカス位置を検出するようにしてもよく、あるいは、大きな開口を有する遮音板を超音波射出系5内に配置し、且つ複数の開口を有する遮音板を超音波受信系6内に配置して、同様に複数点での各フォーカス位置を検出するようにしてもよい。

【0026】なお、上記の実施の形態では、超音波を用いてウェハのフォトレジスト表面のフォーカス位置を検出したが、超音波を用いてフォトレジスト表面の傾斜角を検出するレベルセンサを用いてもよい。このレベルセンサでは、ウェハの表面にはほぼ平行に進む超音波を照射して、反射される超音波の集音位置を検出すればよい。

【0027】なお、本発明は上述の実施の形態に限定されず、本発明の要旨を逸脱しない範囲で種々の構成を取り得ることは勿論である。

【0028】

【発明の効果】本発明の投影露光装置によれば、マスクのパターン像を液体を介して基板の表面に露光するため、基板表面における露光光の波長を実質的に空気中ににおける波長の液体の屈折率の逆数倍に短波長化できる。また、超音波方式の面位置検出装置により基板表面の光軸方向の位置を検出するため、光学式の面位置検出装置では面位置の検出が困難な液体中においても、その位置を高精度に検出することができる。

【0029】また、面位置検出装置が、感光材料の表面の投影光学系の光軸方向の位置を検出する場合には、その検出情報に基づいて投影光学系の像面に対してその感

光材料の表面を高精度に合わせ込むことができる。また、投影光学系の基板側の光学素子の先端部とその基板の表面との間を満たすように液体が供給される場合には、露光光を空気中の $1/n$ 倍（nは液体の屈折率）に短波長化できる、また、投影光学系の鏡筒が液体に接触しないため、投影光学系の鏡筒が腐食しにくくなるという利点がある。

【0030】また、液体が、水である場合には、その入手が容易であるという利点がある。液体が、有機溶媒（例えばアルコール、セダー油等）である場合には、投影光学系の鏡筒が腐食しにくいという利点がある。さらに、液体としてセダー油を用いる場合には、その屈折率が1.5と水（屈折率1.3）等に比べて大きく、露光光をより短波長化することができる。

【0031】また、基板を保持してこの基板を投影光学系の光軸に垂直な平面上で位置決めする基板ステージと、面位置検出装置の検出結果に基づいてその基板の投影光学系の光軸方向の位置を制御する高さ制御ステージとを備える場合には、投影光学系の像面を基板表面上の露光位置に合わせ込むことができる。

【図面の簡単な説明】

【図1】(a)は本発明の実施の形態の一例の投影露光装置を示す概略構成図、(b)は図1(a)の側壁8近傍を示す拡大図である。

【図2】(a)は図1(a)の投影露光装置下部の構成を示す部分拡大図、(b)は図2(a)のB部の拡大図である。

【図3】ウェハW上のフォトレジスト表面のフォーカス位置Zとフォーカス信号Dとの関係を示す図である。

【符号の説明】

W ウエハ

R レチクル

PL 投影光学系

1 照明光学系

2 液体供給回収系

3 鏡筒

4 レンズ

5 超音波射出系

6 超音波受信系

7 液体

8 側壁

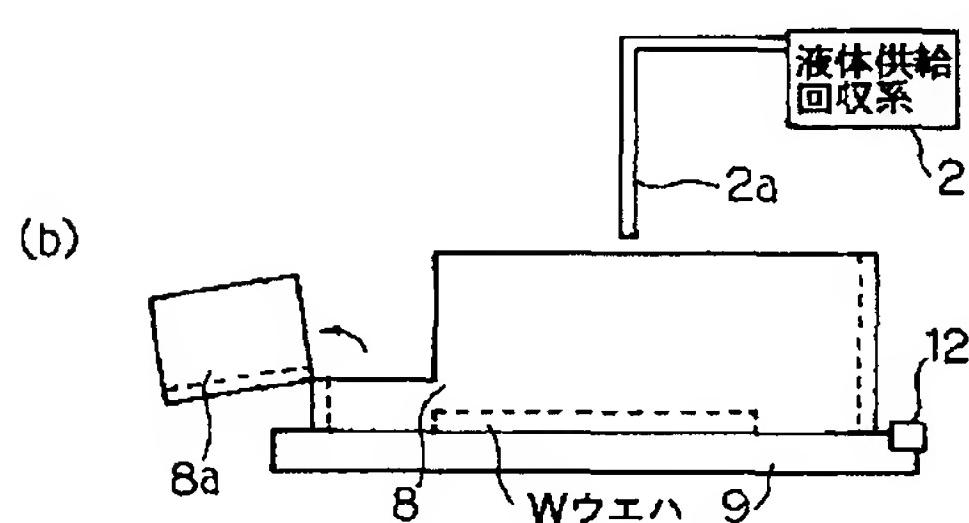
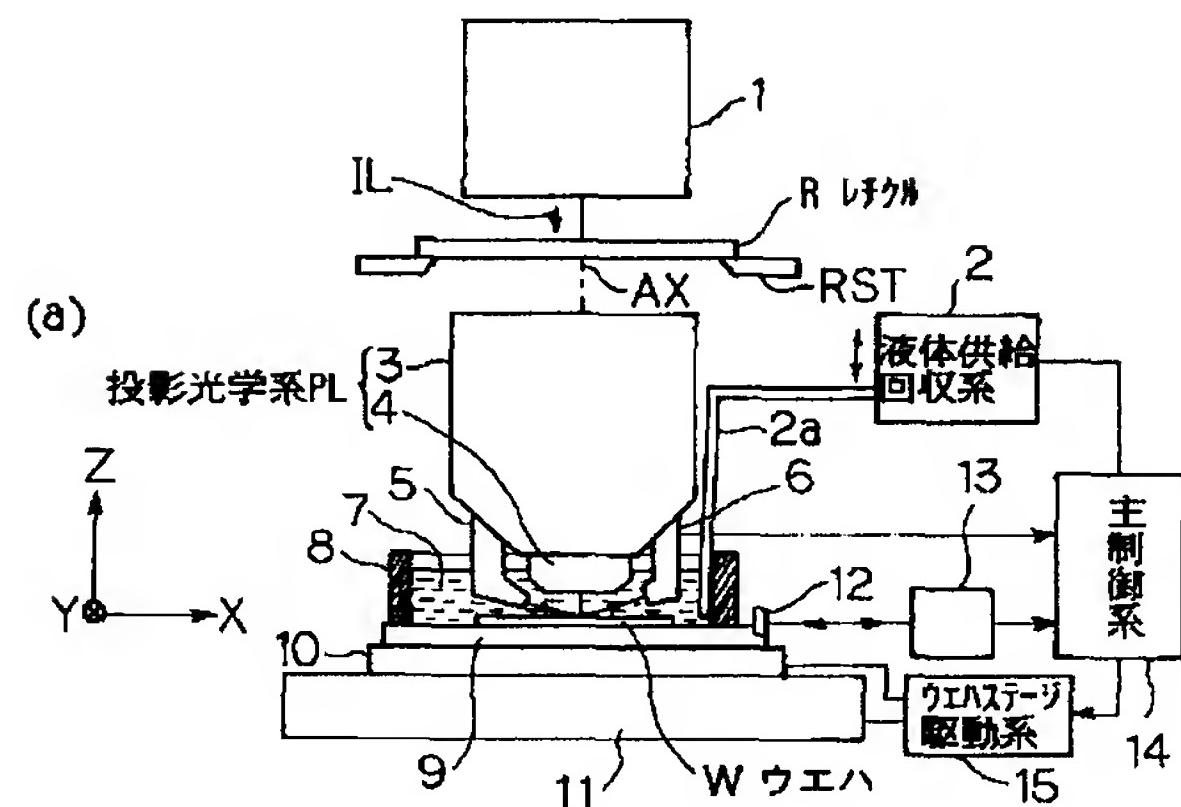
9 試料台

10 Zステージ

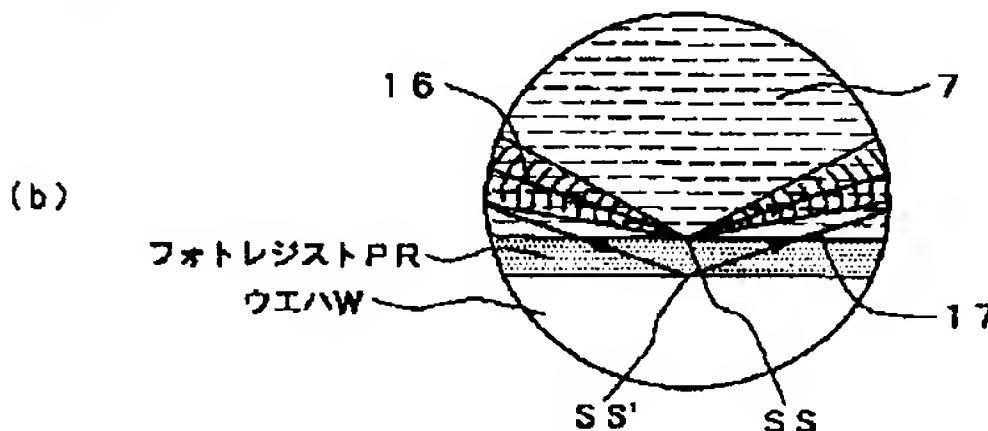
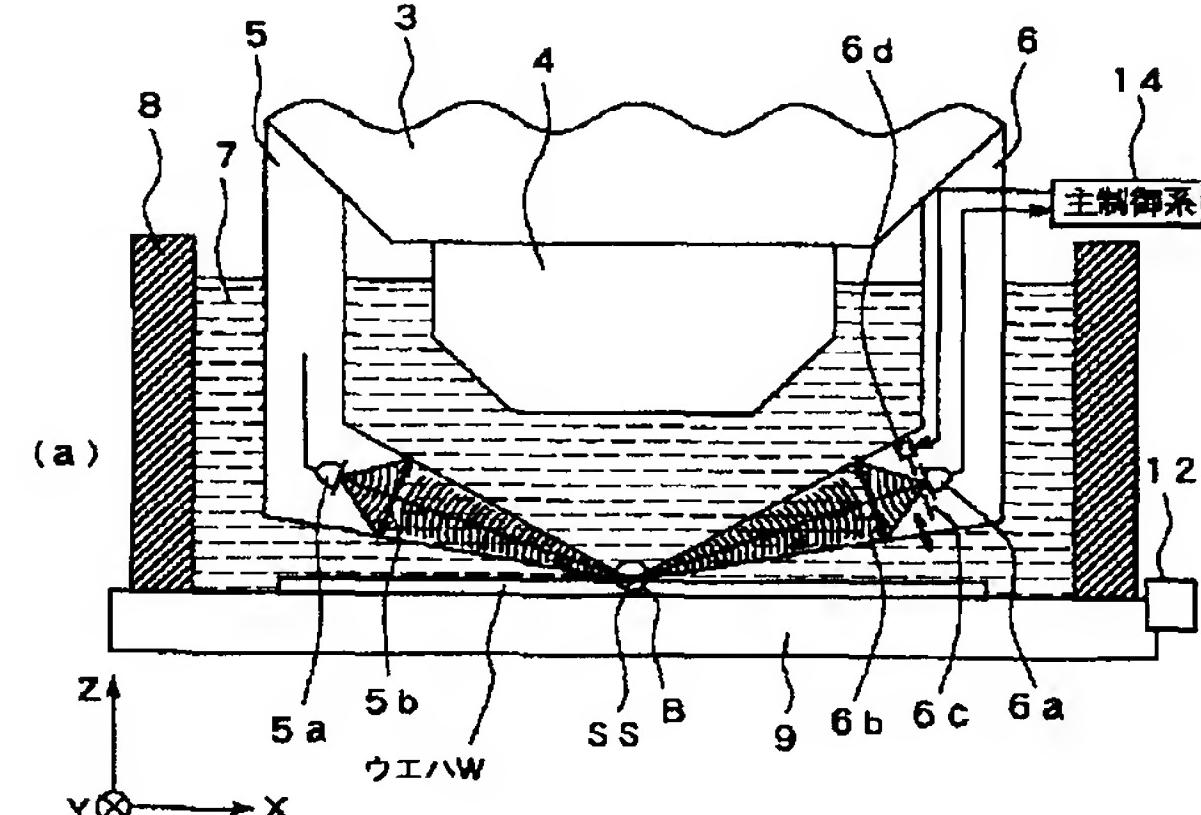
14 主制御系

15 ウエハステージ駆動系

【図1】



【図2】



【図3】

